none; however, considerable investigation has failed to show definitively whether this substance is merely a different ratio of the herqueinone isomers and desoxyherqueinone or contains different types of isomers. The mass spectrum shows the presence of desoxyherqueinone.

For isolation of herqueinone, a 1-g sample of crude product was shaken with 200 ml of benzene for several hours, and the crude "norherqueinone" (250 mg) was removed by filtration. The filtrate was applied to a column of 15 g of Florex XXS, and the benzene was followed by 100 ml of 10% acetone in benzene. The first 25–30 ml of eluate contained most of the red color and yielded 632 mg of red crystalline solid; the remaining eluate yielded 103 mg of dark red solid from which "pure" herqueinone could be obtained only after rechromatography. Two crystallizations from $CHCl_3$ of material from the first eluate yielded 405 mg of soft, copper-colored needles, mp 220–222°. Additional crystallization yields material of mp 222–223° dec, the melting point reported previously[4] for the best material.

For preparation of the samples of herqueinone used for nmr spectra (Figure 1), a sample of mp 222–223° was chromatographed on Florex XXS, and eluted in ten fractions with 3% acetone in benzene. All fractions melted at 222–223°. Fraction 1 was crystallized once from $CHCl_3$, mp 222–223°, and used for curve A, Figure 1. Fractions 5–10 combined were crystallized twice from ethanol, mp 222–223°, and used for curve B, Figure 1.

Norherqueinone used for the nmr spectrum (Table I) was crystallized six times from glacial acetic acid: mp 273–275° (evacuated capillary) (lit.[3] mp 279° dec).

TABLE VII

Desoxynorher-queinone	Desoxyher-queinone	Norher-queinone	Herqueinone
14	47		29
2	10		60
22	68	1	78
21	66	1	85
26	3	6	5

Benzene-Isoluble Pigments.—In addition to the lot of pigments whose spectrum is described in Table VI, five additional lots were examined. For these lots, ratios of peak heights for the molecular ions of interest are shown in Table VII.

Isoherqueinone.—A solution of 100 mg of herqueinone in 10 ml of dry acetone, to which was added 500 mg of anhydrous K_2CO_3, was heated under reflux for 1 hr. After the cooled solution had been diluted with 50 ml of water and acidified, the orange precipitate was collected. Two crystallizations from 95% ethanol yielded 33 mg of orange needles: mp 247.5–250.5° (lit.[3] mp 248–249°); $[\alpha]^{23}D$ 0 ± 30°; $[\alpha]^{23}_{Hg}$ 200 ± 100° (c 0.9 mg/ml, ethanol).

A 10-mg sample of isoherqueinone was dissolved in 2 ml of 1 *N* NaOH and allowed to stand for 5 min, and the pH was reduced to 4. The yellow solid which precipitated turned orange in *ca.* 1 min. The orange solid was collected and crystallized from 95% ethanol to yield 4 mg of orange needles, mp 247–248.5°, no depression on admixture with an authentic sample of isoherqueinone. There was a large depression in melting point on admixture with herqueinone.

The mass spectrum of isoherqueinone was identical with that of herqueinone, and desoxyherqueinone was always present.

Chemical Reduction of Isoherqueinone.—To a solution of 40 mg of isoherqueinone in 5 ml of glacial acetic acid was added 80 mg of zinc dust. After this mixture had been shaken mechanically for 30 min it was filtered into 15 ml of water. The resultant mixture was allowed to stand for 45 min, and the precipitated yellow solid was collected and washed with 10 ml of 1 *N* hydrochloric acid. The dried product (30 mg, mp 120–140°), after one crystallization from acetone and one from benzene, yielded 19 mg of yellow crystals: mp 246–248°; $[\alpha]^{25}D$ 62 ± 10° (*c* 5 mg/ml, acetic acid). There was no depression in melting point on admixture with authentic desoxyherqueinone of mp 246–248°; both uv and ir spectra were likewise identical (lit.[3] for desoxyherqueinone, mp 240–241°; $[\alpha]^{22}D$ 64°).

Registry No.—**4**, 22185-93-9; **5**, 22212-27-7.

A Stereoselective Synthesis of Hydroazulenes

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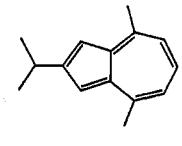
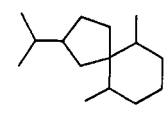
A new synthesis of hydroazulenes based on the cyclization of unsaturated aldehydes is described. The synthesis employs methylated hydrindanones as the starting materials and proceeds *via* solvolytic fragmentation of the corresponding oxime derivatives to the related unsaturated nitriles using *p*-toluenesulfonyl chloride in refluxing pyridine. Reduction to the required aldehyde derivatives was smoothly effected using diisobutylaluminum hydride. Treatment of the aldehydes with silica gel afforded the desired hydroazulenic alcohols.

An interest in the structure and stereochemistry of the vetivane sesquiterpenes prompted us to examine stereoselective synthetic routes to hydroazulenes related to vetivazulene (I).[2] In the course of this work we developed such a route based on the cyclization of unsaturated aldehydes (*e.g.*, **10** → **11**).[3] We subsequently discovered that the vetivane carbon skeleton must be reformulated in terms of the spiro[4.5]decane system II.[4] While this discovery precludes an application of our new hydroazulene synthesis to vetivane sesquiterpenes, we nonetheless present an account of our experimental findings at this time, since (a) the synthetic scheme entails several novel features of intrinsic interest, and (b) applications to other hydroazulenic sesquiterpene types[5] can be envisioned with slight modifications of the scheme.



I



II

The hydrindanone **1**[6] (Scheme I) served as our starting point for these studies. Selective methylation[7] followed by catalytic hydrogenation afforded a mixture of the *cis* and *trans* fused hydrindanones **4c** and

(1) (a) National Science Foundation Predoctoral Fellow, 1964–1966; National Institutes of Health Predoctoral Fellow, 1966–1967; (b) National Institutes of Health Predoctoral Fellow, 1966–1969.

(2) A. St. Pfau and P. A. Plattner, *Helv. Chim. Acta*, **22**, 202 (1939).

(3) J. A. Marshall and N. H. Andersen, *Tetrahedron Lett.*, 1219 (1967).

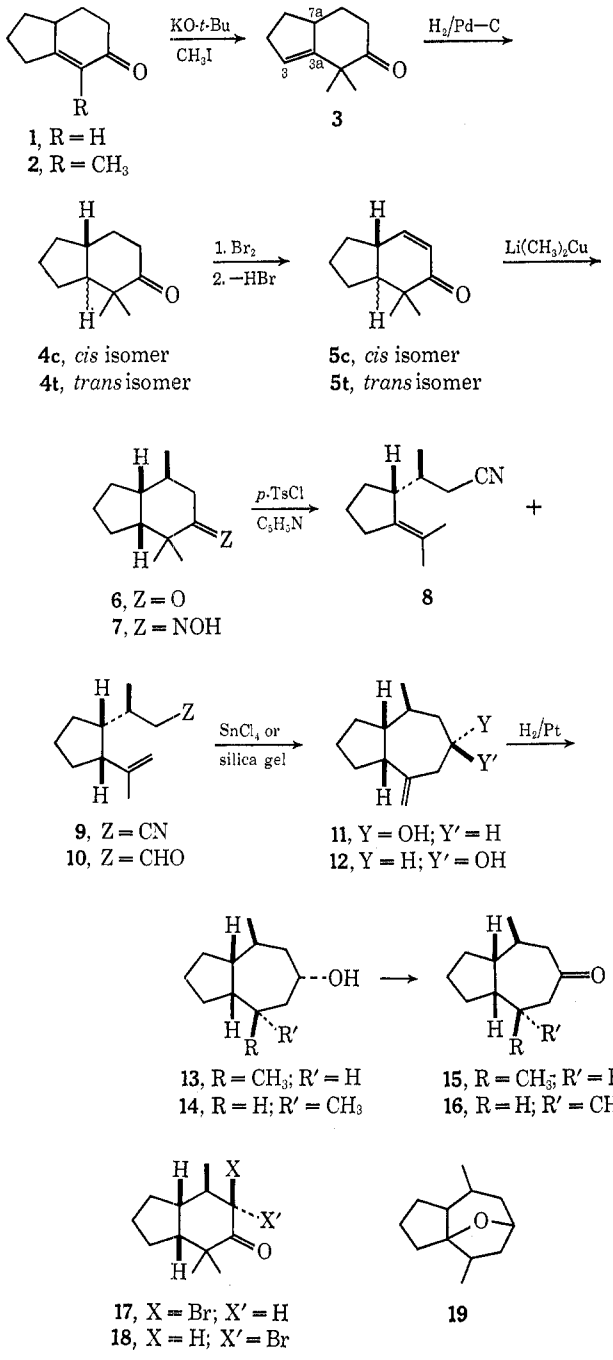
(4) J. A. Marshall, N. H. Andersen, and P. C. Johnson, *J. Amer. Chem. Soc.*, **89**, 2748 (1967); J. A. Marshall and P. C. Johnson, *ibid.*, **89**, 2750 (1967); *J. Org. Chem.*, **34**, 192 (1969).

(5) *Cf.* P. de Mayo, "Mono- and Sesquiterpenoids," Interscience Publishers, New York, N. Y., 1959, pp 244–276.

(6) G. Stork, A. Brizzolara, H. Landesman, J. Szmuszkovicz, and R. Terrell, *J. Amer. Chem. Soc.*, **85**, 207 (1963).

(7) *Cf.* J. A. Marshall and N. H. Andersen, *J. Org. Chem.*, **31**, 667 (1966).

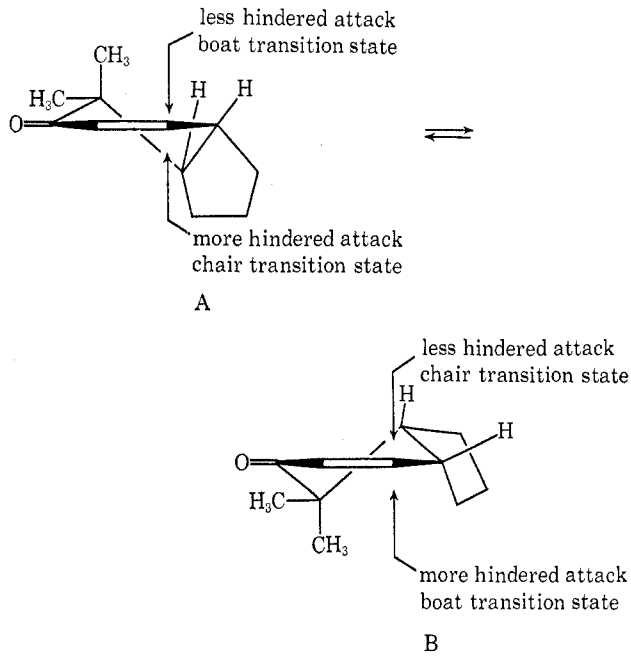
SCHEME I



4t, with the former predominant.[8] Direct comparison of this material with the mixture (mainly 4t) prepared *via* reduction–methylation[6] of the methylhydrindanone 2 confirmed the stereochemical assignment of the hydrogenation product.[8]

The *cis*-hydrindanone 4c, purified *via* the semicarbazone derivative, afforded the unsaturated ketone 5c upon bromination followed by dehydrobromination. Alternatively, the mixture of *cis* and *trans* isomers 4c and 4t could be employed in the bromination–dehydrobromination sequence. Equilibration of the resulting mixture of *cis–trans* enone isomers 5c and 5t in alkali yielded material highly enriched (98% 5c, 2% 5t) in the former. Lithium dimethylcopper[9] attacked enone 5c in a highly selective fashion to give ketone 6 in excellent yield.

We initially assigned the indicated stereochemistry to ketone 6 from a consideration of the factors which influence the conjugate addition reaction leading to its formation.[7] As shown below, the methylene groupings of the *cis* fused cyclopentane ring tend to shield the concave face of enone 5c in both conformers A and B. Therefore, attack at C-7 should preferentially take place on the convex face of the hydrindanone. Of the two possible transition states resulting from this mode of attack, the one derived from conformer B should be of lowest energy, since the chair form of the cyclohexene ring will be thereby maintained.



Experimental verification of stereochemistry for ketone 6 came from bromination studies wherein two isomeric α-bromo ketones 17 and 18 were formed in nearly equal amounts. The former, an axial bromo ketone according to its infrared spectrum, slowly isomerized in acid to the latter, an equatorial bromo ketone. Of the two possible methylated hydrindanones derived from the *cis* fused enone 5c, only isomer 6 would be expected to afford an appreciable percentage of axial α-bromo ketone. In keeping with this analysis, the isomeric *cis* fused hydrindanone 21 afforded only an equatorial α-bromo ketone upon bromination under the conditions employed for ketone 6. The nmr spectra of the isomeric bromo ketones gave further support to the assigned stereochemistry.

The oxime derivative 7 underwent solvolytic fragmentation upon treatment with *p*-TsCl in refluxing pyridine[10] to give a 60:40 mixture of the isopropenyl and isopropylidene nitriles 9 and 8. This ratio changed slightly, but did not improve, with variations in tem-

(8) Space limitations preclude a discussion of the fairly extensive studies relating to this point. Pertinent details are presented in the Ph.D. Thesis of Niels H. Andersen, "Approaches to the Synthesis of Vetivane Sesquiterpenes," Northwestern University, Jan. 1967.

(9) H. O. House, W. L. Respess, and G. M. Whitesides, *J. Org. Chem.*, **31**, 3128 (1966).

(10) *Cf.* J. Klinot and A. Vystrcil, *Collect Czech. Chem. Commun.*, **27**, 377 (1962); R. M. Carman and D. Cowley, *Aust. J. Chem.*, **18**, 213 (1965).

perature, solvent, sulfonyl chloride, and added base.[8,11] At lower temperature, an appreciable quantity of the lactam derivative was formed. Further treatment of this material with *p*-TsCl in refluxing pyridine yielded the nitriles **9** and **8** in the aforementioned ratio.[8]

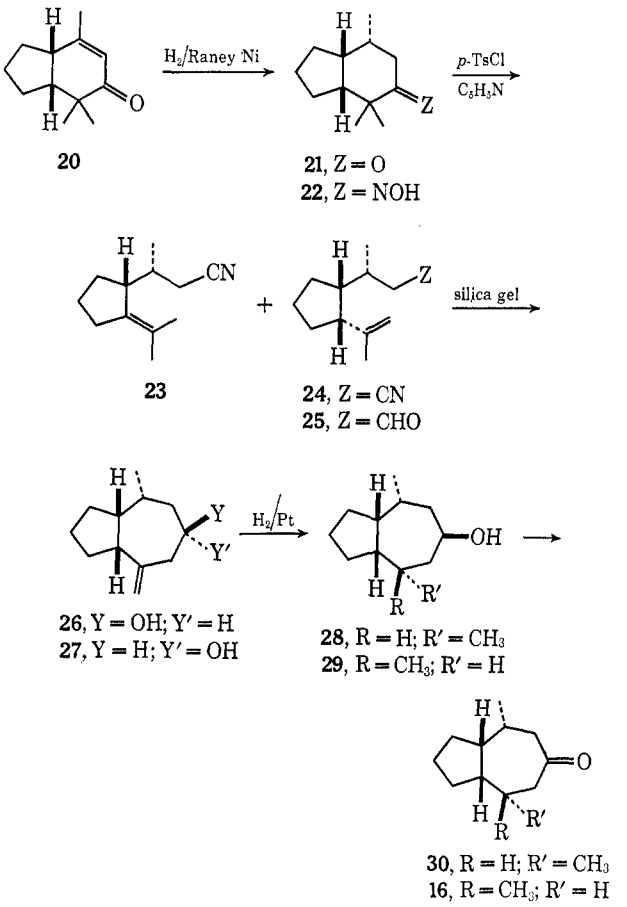
Of the numerous routes to aldehyde **10** examined,[8] the direct reduction of nitrile **9** with diisobutylaluminum hydride proved by far the most satisfactory. Treatment of this aldehyde with stannic chloride in benzene[12] for brief periods smoothly afforded the unsaturated alcohols **11** and **12** as an 88:12 mixture in 90% yield. Prolonged reaction times or the use of wet benzene gave rise to the tricyclic ether **19**. Evidently, HCl isomerizes the exocyclic double bond and catalyzes intramolecular ether formation in these cases. This undesired side reaction could be circumvented by treating aldehyde **10** with silica gel, whereupon the alcohols **11** and **12** were obtained in essentially the same ratio (89:11) as before, but none of the tricyclic ether **19** was produced. We defer further discussion of these cyclization experiments to the end of this report.

Hydrogenation of the unsaturated alcohol **11** led to a 55:40 mixture of the epimers **13** and **14**. Jones oxidation[13] of each yielded the corresponding ketones **15** and **16**, respectively. The stereochemistry of these ketones became clear upon completion of the sequence outlined in Scheme II, which likewise afforded the *dl* isomer **16** as one of two epimeric ketonic products.

The third *cis* fused isomer, **30**, was prepared as indicated in Scheme II starting with the trimethylhydrindanone **21**. This latter ketone was secured *via* hydrogenation of the conjugated ketone **20** derived from dehydrobromination of the bromo ketone mixture (**17** and **18**) mentioned earlier in connection with the structure assignment of ketone **6**. The selection of Raney nickel as the catalyst for this hydrogenation evolved from our findings that Pd and Pt catalysts caused prior migration of the carbon–carbon double bond, leading ultimately to mixtures of *cis* and *trans* fused hydrindanones.[8,11]

Solvolytic fragmentation of the oxime derivative **22** with *p*-TsCl in refluxing pyridine afforded an 80:20 mixture of the isopropylidene and isopropenyl nitriles **23** and **24**. Just as in the case of the analogous reaction of oxime **7**, variations in reaction conditions failed to improve this unfavorable isomer ratio.[11] The remainder of the synthetic sequence followed along the exact lines discussed above for nitrile **9**. Thus, reduction with diisobutylaluminum hydride afforded the aldehyde **25**, which smoothly cyclized to alcohol **26** upon treatment with silica gel. In this case, only a trace of the epimeric alcohol **27** could be detected. Hydrogenation of the unsaturated alcohol **26** led to a mixture (*ca.* 60:40) of the epimers **29** and **28**, which yielded the corresponding ketones **16** and **30** upon oxidation with Jones reagent.[13] The major ketone thus secured proved identical with one of the ketones

SCHEME II



prepared from hydrindanone **6** (Scheme I) and must therefore be the *dl* isomer **16**.

The highly selective nature of the cyclization of unsaturated aldehydes **10** and **25** deserves special mention. In the first place, only the exocyclic double bond isomers could be detected in the alcohol products formed under optimum cyclization conditions. Prolonged exposure to stannic chloride resulted in double-bond isomerization, thus showing that the observed preferences do not merely reflect thermodynamic control. Furthermore, silica gel would not be expected to effect equilibration of isolated carbon–carbon double bonds. A plausible explanation of the observed results can be advanced on the basis of stereoelectronic concepts. Thus, as shown in Chart I, the tertiary (C-1) allylic C–H bond of the cationic complex derived from aldehyde **10** and the isopropenyl double bond adopt a nearly coplanar arrangement in the conformer favorable for cyclization. On the other hand, one of the allylic C–H bonds of the vinylic methyl grouping can quite readily assume a perpendicular orientation to this double bond, thereby enabling proton loss and C–C bond formation to take place in concert. The same situation would pertain for aldehyde **25**.

A second point of interest with regard to these aldehyde cyclizations relates to the stereochemistry of the alcohols thereby obtained. In each case, one epimer decisively predominates. The intrinsic conformational uncertainties of cycloheptane derivatives[14] have thus far stymied our efforts to prove the relative

(11) Space limitations preclude a discussion of the fairly extensive studies relating to this point. Pertinent details are presented in the Ph.D. Thesis of Porter C. Johnson, "The Structure and Total Synthesis of β-Vetivone," Northwestern University, June 1969.

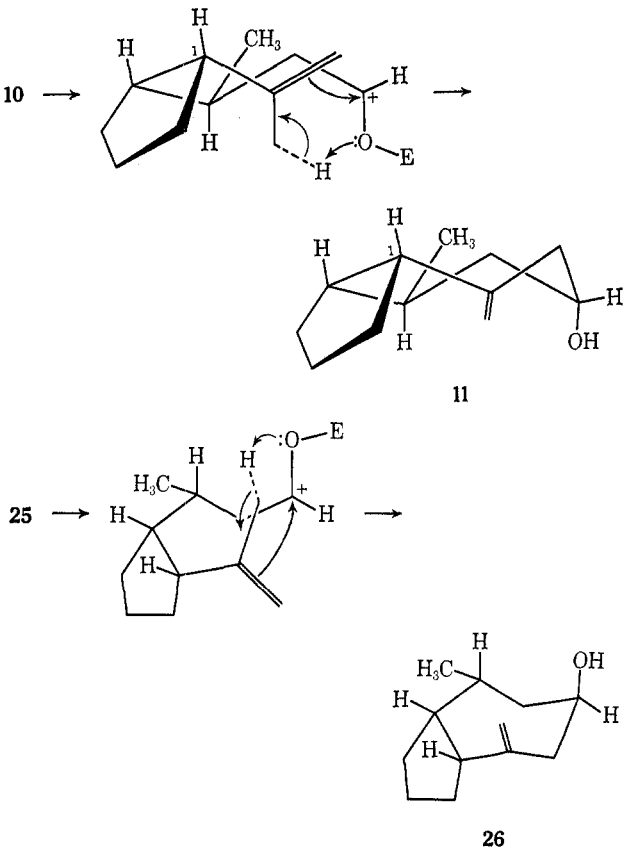
(12) *Cf.* D. J. Goldsmith and C. J. Cheer, *J. Org. Chem.*, **30**, 2264 (1965).

(13) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. L. Weedon, *J. Chem. Soc.*, 39 (1946).

(14) *Cf.* J. B. Hendrickson, *Tetrahedron*, **19**, 1387 (1963).

CHART I

CATIONIC CYCLIZATION OF ALDEHYDES **10** AND **25** (E = ELECTROPHILE)



stereochemistry of these alcohols. However, the spectral data and chemical transformations thus far examined[8] can be reconciled with the indicated structures. This orientation would suggest a concerted cyclization as depicted in Chart I, whereby the aldehyde oxygen acts as an internal base and assists in the removal of the allylic hydrogen. A similar picture can be envisioned for aldehyde **25**. These transition states would also explain the exclusive formation of exocyclic double bond isomers in the alcohol products. In each case, the secondary methyl group, by virtue of steric interactions in the probable cyclization reaction transition states, would control the orientation of the carbonyl oxygen and thus the stereochemistry of the alcohol products. Chart I shows favorable conformations of the two isomers leading to the assigned products.

Experimental Section[15]

4,4-Dimethyl-3a*c*,6,7,7a*r*-tetrahydro-5(4H)-indanone (4c).[15d]—A solution of 92.4 g (0.678 mol) of ketone **1**[6] (86% pure by gas chromatography), 244 ml of methyl iodide, and 610 ml of *t*-butyl alcohol was cooled to 2° and 2.0 l. of 0.92 *M* KO-*t*-Bu in *t*-butyl alcohol was added with stirring over 45 min to maintain the temperature below 20°.[15a] After 30 min at 15° and 90 min at room temperature, the solution was filtered and concentrated under reduced pressure, and the product was isolated with benzene–ether[15b] and distilled, affording 101.3 g (85%) of impure ketone **3** (70% by gas chromatography), bp 111–121° (16 mm).

The semicarbazone derivative of this ketone exhibited mp 214–216° after recrystallization from 2:1 methanol–isopropyl alcohol.

Anal.[15c] Calcd for $C_{12}H_{19}N_3O$: C, 65.12; H, 8.63; N, 19.00. Found: C, 65.3; H, 8.6; N, 19.2.

The ketone **3** was obtained by treating the semicarbazone derivative with 3 mol equiv of oxalic acid at reflux in 3:1 methanol–water for several hours.[15a] Material of 98% purity (gas chromatographic analysis) was thus secured: $n^{27}D$ 1.4978; ir λ_{max}^{film} 5.84 (CO), 6.09, 7.22, 7.33, 8.79, 9.23, and 12.27 μ; nmr $\delta_{TMS}^{CCl_4}$ 5.36 (4 lines, $J_{3,2}$ = 2 Hz, $J_{3,7a}$ = 2 Hz, H-3) and 1.21 and 1.20 ppm (C-4 methyls).

A 109.4-g sample of the crude distilled hydrindanone **3** described above (70% pure) and 2.50 g of 5% palladium on carbon in 150 ml of ethanol was shaken with 3–4 atm of hydrogen in a Parr apparatus for 4 hr. The mixture was filtered and distilled, affording 108.5 g (98%) of impure ketone **4c** (an 85:15 mixture of *cis* and *trans* isomers **4c** and **4t** containing *ca.* 60% **4c** according to the gas chromatogram), bp 117–120° (17 mm).

A 91.5-g sample of this ketone mixture was treated with 89.0 g of semicarbazide hydrochloride in 400 ml of methanol and 270 ml of water at reflux for 5 min, at which point 153 ml of pyridine was added and the mixture was heated for an additional 15 min and filtered while still hot.[15a] The solid was recrystallized from isopropyl alcohol, affording 34.2 g of the semicarbazone derivative of hydrindanone **4c**, mp 211–213°. The analytical sample exhibited mp 218–221° after recrystallization from 2:1 methanol–isopropyl alcohol.

Anal.[15c] Calcd for $C_{12}H_{21}N_3O$: C, 64.65; H, 9.48; N, 18.81. Found: C, 64.7; H, 9.3; N, 18.6.

A 34.2-g sample of the above semicarbazone derivative, 300 ml of hexane, 300 ml of 10% aqueous sulfuric acid, and 730 ml of methanol were heated at reflux for 2 hr.[15a] The product was isolated with hexane,[15b] affording 26.5 g (99%) of hydrindanone **4c**: bp 118–119°[9] (17 mm); 94% purity according to gas chromatography; ir λ_{max}^{film} 5.85 (CO), 7.21, 7.32, 7.50, 8.79, 9.10, 9.63, 10.14, 10.87, and 11.60 μ; nmr $\delta_{TMS}^{CCl_4}$ 0.98 and 1.29 ppm (C-4 methyls); $n^{25}D$ 1.4815.

6*t*-Bromo-4,4-dimethyl-3a*c*,6,7,7a*r*-tetrahydro-5(4H)-indanone.[15d]—To a solution of 26.5 g (0.160 mol) of ketone **4c** in 160 ml of acetic acid was added 50.0 ml of 3.29 *M* bromine in acetic acid over a 30-min period with cooling such that the temperature remained at 10°.[15a] After 10 min, the solution was poured into 800 ml of water with efficient stirring, whereupon the product crystallized. The solid was filtered, washed with aqueous sodium bicarbonate and water, and dried, affording 36.1 g (92%) of bromo ketone: mp 67–79°; ir λ_{max}^{KBr} 5.80 (CO), 7.20, 7.30, 9.11, 9.32, 9.88, 10.23, 10.72, 11.32, and 14.01 μ; nmr $\delta_{TMS}^{CCl_4}$ 5.14 (4 lines, $J_{6,7t}$ = 14 Hz, $J_{6,7c}$ = 7 Hz, H-6) and 1.33 and 1.04 ppm (C-4 methyls). The analytical sample, mp 88.5–89.5°, was secured after sublimation (60°, 0.1 mm) of this material.

Anal.[15c] Calcd for $C_{11}H_{17}BrO$: C, 53.89; H, 6.99; Br, 32.58. Found: C, 53.9; H, 7.1; Br, 32.5.

4,4-Dimethyl-3a*c*,7a*r*-dihydro-5(4H)-indanone (5c).[15d]—A mixture containing 36.08 g of calcium carbonate in 360 ml of N,N-dimethylacetamide was heated at reflux for 35 min,[16] cooled, and filtered.[15a] The product was isolated with heptane[15b] and distilled, affording 21.81 g (90%) of ketone **5c**: bp 114–121° (11 mm); ir λ_{max}^{film} 3.34 (vinyl CH), 5.97 (CO), 6.17 (C=C), 6.80, 6.89, 7.11, 7.22, 8.49, 8.90, 9.11, 10.84, 11.81, and 12.44 μ; nmr $\delta_{TMS}^{CCl_4}$ 6.32 ($J_{6,7}$ = 10.6 Hz, $J_{6,7a}$ = 2.7 Hz, $J_{7,7a}$ = 2.5 Hz, $\Delta\nu_{6,7}$ = 43.1 Hz, H-6, H-7), 2.98 ($W_{1/2}$ = 14 Hz, H-7a), and 1.20 and 1.06 ppm (C-4 methyls).

The oxime derivative exhibited mp 123–123.5° after recrystallization from aqueous methanol.

Anal.[15c] Calcd for $C_{11}H_{17}NO$: C, 73.71; H, 9.56; N, 7.81. Found: C, 73.8; H, 9.55; N, 7.8.

Equilibration of Ketones 5c and 5t.—A 7:3 mixture of ketones **5c** and **5t** (25 mg) and 50 mg of sodium carbonate in 3 ml of methanol and 1 ml of water was heated at reflux for 19 hr.[15a] The product was isolated with ether–hexane,[15b] affording material containing 98% of ketone **5c**, 2% of ketone **5t**, and a trace

(15) (a) The apparatus described by W. S. Johnson and W. P. Schneider ["Organic Syntheses," Coll. Vol. 4, John Wiley & Sons, Inc., New York, N. Y., 1963, p 132] was used to maintain a nitrogen atmosphere. (b) The isolation procedure consisted of thorough extractions with the specified solvent, washing the combined extracts with saturated brine solution, and drying the extracts over anhydrous magnesium sulfate. The solvent was removed from the filtered extracts under reduced pressure on a rotary evaporator. (c) Microanalyses were performed by Micro-Tech Laboratories, Inc., Skokie, Ill. (d) Relative stereochemistry is designated by "*c*" and "*t*" to denote a *cis* or *trans* relationship to some reference ("*r*") substituent according to Beilstein ("Handbuch der Organischen Chemie," E III, Vol. VI, Part 7, p x).

(16) *Cf.* G. Green and A. Long, *J. Chem. Soc.*, 2532 (1961).

of what is presumably the β,γ-unsaturated isomer (gas chromatographic analysis).

4,4,7*c*-Trimethyl-3a*c*,6,7,7a*r*-tetrahydro-5(4H)-indanone (6).[15d]—Lithium dimethylcopper was prepared following the procedure of House, *et al.*,[9] by the addition of 520 ml of 1 *M* ethereal MeLi to 51.1 g (0.268 mol) of CuI in 2 l. of ether at 0°.[15a] A solution of 21.81 g (0.133 mol) of ketone **5c** in 100 ml of ether was added with stirring over 10 min, and the mixture was stirred for an additional hour at 0° and poured into cold saturated ammonium chloride solution. The product was isolated with ether,[15b] affording 22.85 g (96%) of material, bp 128–130° (18 mm), containing 84% of ketone **6** and no more than 4% of the 7*t*-methyl isomer according to the gas chromatogram: ir λ_{max}^{film} 5.85 (CO), 7.21, 7.31, 8.04, 8.89, 9.10, and 9.63 μ; nmr $\delta_{TMS}^{CCl_4}$ 1.27, 0.97 (C-4 methyls), and 1.01 ppm (d, J = 5 Hz, C-7 methyl).

The oxime derivative **7** was prepared by heating 4.18 g (23.2 mmol) of the above ketone, 3.48 g (50.1 mmol) of hydroxylamine hydrochloride, 46.4 ml of 95% ethanol, and 40.5 ml of pyridine at reflux for 3 hr.[15a] The solution was treated with 18 ml of methanol and 54 ml of water and cooled, affording 3.43 g (76%) of crystalline oxime, mp 147–149°. The analytical sample, mp 149.5°, was obtained after one recrystallization from 2:1 methanol–isopropyl alcohol and sublimation at 90° (0.2 mm).

Anal.[15c] Calcd for $C_{12}H_{21}NO$: C, 73.79; H, 10.84; N, 7.17. Found: C, 73.95; H, 10.5; N, 6.95.

Fragmentation of Oxime 7.—A solution of 4.58 g (23.4 mmol) of oxime **7** and 12.49 g (65.5 mmol) of *p*-TsCl in 350 ml of pyridine was heated at reflux for 3 hr.[15a] The cooled solution was poured into 1.2 l. of 2% aqueous sodium hydroxide and the product was isolated with heptane,[15b] affording 3.51 g (84%) of a mixture containing 53% of the isopropenyl nitrile **9** and 45% of the isopropylidene isomer **8** according to the gas chromatogram.

These isomers were separated by chromatography on 440 g of 10% silver nitrate impregnated silica gel.[17] The isopropylidene isomer **8** (1.0 g) was obtained in the early benzene fractions: bp 70° (0.04 mm); ir λ_{max}^{film} 4.45 (CN), 6.87, 7.00, 7.32, and 7.28 μ; nmr $\delta_{TMS}^{CCl_4}$ 1.62 ($W_{1/2}$ = 5 Hz, vinyl CH_3's) and 0.95 ppm (d, J = 6.1 Hz, CH_3).

Anal.[15c] Calcd for $C_{12}H_{19}N$: C, 81.30; H, 10.80; N, 7.90. Found: C, 81.5; H, 10.8; N, 7.9.

The later benzene fractions yielded the isopropenyl isomer **9** (1.71 g): bp 70° (0.04 mm); ir λ_{max}^{film} 3.26 (vinyl CH), 4.46 (CN), 6.09 (C=C), 6.86, 7.00, 7.24, 7.50, and 11.20 μ; nmr $\delta_{TMS}^{CCl_4}$ 4.67 (m, vinyl H), 1.70 ($W_{1/2}$ = 4 Hz, vinyl CH_3), and 1.03 (d, J = 5.5 Hz, CH_3).

Anal.[15c] Calcd for $C_{12}H_{19}N$: C, 81.30; H, 10.80; N, 7.90. Found: C, 81.5; H, 11.0; N, 7.8.

***rel*-3(*S*)-[2(*R*)-Isopropenyl-1(*R*)-cyclopentyl]butanal (10).**—To a solution of 695 mg (3.92 mmol) of nitrile **9** in 60 ml of hexane at −60° was added 4.7 ml of 0.97 *M* diisobutylaluminum hydride in hexane with stirring.[15a] After 3 hr at room temperature, the solution was treated with 39 ml of saturated ammonium chloride solution and, after an additional 20 min, 14 ml of 5% aqueous sulfuric acid was added. The product was then immediately isolated with ether–hexane,[15b] affording 598 mg (85%) of aldehyde **10** (90% pure by gas chromatography): ir λ_{max}^{film} 3.68 (aldehyde CH), 5.79 (CO), 6.08 (C=C), 7.24, and 11.23 μ; nmr $\delta_{TMS}^{CCl_4}$ 9.62 (t, J = 2 Hz, aldehyde H), 4.70 (m, vinyl H), 1.71 (vinyl CH_3), and 0.92 ppm (d, J = 5.2 Hz, CH_3).

The 2,4-DNP derivative exhibited mp 118–119° from ethanol.

Anal.[15c] Calcd for $C_{18}H_{24}N_4O_4$: C, 59.99; H, 6.71; N, 15.55. Found: C, 60.2; H, 6.7; N, 15.5.

Cyclization of Aldehyde 10. A. Using Stannic Chloride.—To a solution of 100 mg (0.555 mmol) of aldehyde **10** in 55 ml of benzene at 10° was added 0.17 ml of 0.49 *M* stannic chloride in benzene.[15a] The solution was stirred for 6 min and the product was isolated with ether,[15b] affording a mixture containing 88% of alcohol **11** and 12% of alcohol **12** as judged by gas chromatography.

B. Using Silica Gel.—A 1.35-g (7.60 mmol) sample of aldehyde **10** (93% pure) was chromatographed on 170 g of silica gel. The early 10% ether–benzene fractions afforded 0.90 g (66%) of 6*c*-methyl-2-methylene-1*c*H,7*r*H-bicyclo[5.3.0]decan-4*t*-ol (**11**): ir λ_{max}^{film} 2.96 (OH), 3.25 (vinyl CH), 6.10 (C=C), 6.88, 6.97, 7.24, 8.44, 9.33, 9.61, 9.82, 10.85, 11.23, 11.44, and 12.43 μ: nmr $\delta_{TMS}^{CCl_4}$ 4.85 ($W_{1/2}$ = 2.5 Hz, vinyl H's), 3.97 ($W_{1/2}$ = 11 Hz, H-4), 2.83 (OH), and 0.92 ppm (unresolved, C-6 CH_3).

Anal.[15c] Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.0; H, 11.3.

The later 10% ether–benzene fractions afforded 115 mg (9%) of 6*c*-methyl-2-methylene-1*c*H,7*r*H-bicyclo[5.3.0]decan-4*c*-ol (**12**, 83% pure by gas chromatography): ir λ_{max}^{film} 3.00 (OH), 3.24 (vinyl CH), 6.09 (C=C), 7.25, 7.35, 9.72, and 11.25 μ; nmr $\delta_{TMS}^{CCl_4}$ 4.87 ($\Delta\nu$ = 8 Hz, vinyl H), 3.60 ($W_{1/2}$ = 27 Hz, H-4), and 0.97 ppm (unresolved, C-6 CH_3). A coupling of 4.5 Hz was observed for the C-6 methyl grouping in pyridine as the solvent.

Hydrogenation of Alcohol 11.—A mixture of 890 mg (4.93 mmol) of alcohol **11**, 232 mg of platinum oxide, and 7 ml of ethanol was stirred under 1 atm of hydrogen at room temperature for 2 hr. The mixture was filtered and concentrated, affording 853 mg (95%) of a mixture containing 55% of alcohol **13** and 40% of alcohol **14** according to the gas chromatogram. This mixture was separated by preparative gas chromatography to give, after crystallization from pentane, 156 mg of 2*c*,6*c*-dimethyl-1*c*H,7*r*H-bicyclo[5.3.0]decan-4*t*-ol (**13**): mp 75.5–77°; ir λ_{max}^{KBr} 2.99 (OH), 6.84, 7.00, 7.28, 7.36, 7.47, 7.60, 7.96, 8.24, 8.71, 9.27, 9.68, 10.14, 10.70, 10.97, 12.49, and 13.02 μ; nmr $\delta_{TMS}^{CCl_4}$ 3.97 ($W_{1/2}$ = 13 Hz, H-4), 2.94 (OH), and 0.88 ppm (d, J = 5.3 Hz, CH_3's). The analytical sample, mp 77–77.5°, was obtained upon sublimation at 60° (0.2 mm).

Anal.[15c] Calcd for $C_{12}H_{22}O$: C, 79.06; H, 12.16. Found: C, 79.25; H, 12.1.

The second component, 2*t*,6*c*-dimethyl-1*c*H,7*r*H-bicyclo[5.3.0]-decan-4*t*-ol (**14**), was obtained as an oil: ir λ_{max}^{film} 2.99 (OH), 6.96, 7.25, 7.65, 8.52, 9.15, 9.49, 9.82, 10.34, 10.42, and 11.20 μ; nmr $\delta_{TMS}^{CCl_4}$ 3.93 ($W_{1/2}$ = 13 Hz, H-4), 3.03 (OH), and 0.92 ppm (unresolved, CH_3's).

2*c*,6*c*-Dimethyl-1*c*H,7*r*H-bicyclo[5.3.0]decan-4-one (15).[15d]—A 227-mg (1.25 mmol) sample of alcohol **13** was oxidized with 0.31 ml of Jones reagent,[13] affording 200 mg (89%) of ketone **15**: ir λ_{max}^{film} 5.88 (CO), 6.87, 7.25, 7.77, 7.92, 8.04, 8.4–8.5, 9.61, and 12.3–12.5 μ; $\delta_{TMS}^{CCl_4}$ 0.96 ppm (d, J = 4.0 Hz, CH_3's). The 2,4-DNP derivative exhibited mp 85.5–86.5° from isopropyl alcohol.

Anal.[15c] Calcd for $C_{18}H_{24}N_4O_4$: C, 59.99; H, 6.71; N, 15.55. Found: C, 60.0; H, 6.8; N, 15.5.

2*t*,6*c*-Dimethyl-1*c*H,7*r*H-bicyclo[5.3.0]decan-4-one (16).[15d]—A 109-mg (0.597 mmol) sample of alcohol **14** was oxidized with 0.14 ml of Jones reagent,[13] affording 75 mg (70%) of ketone **16**: ir λ_{max}^{film} 5.87 (CO), 6.87, 7.10, 7.29, 7.49, 7.84, 7.97, 8.88, and 9.33 μ; nmr $\delta_{TMS}^{CCl_4}$ 1.00 ppm (unresolved, CH_3's).

Anal.[15c] Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.0; H, 11.15.

Bromination of Ketone 6.—A solution of 22.84 g (0.127 mol) of ketone **6** (84% pure) of 120 ml of acetic acid was cooled to 10° and 43.5 ml of 3.29 *M* bromine in acetic acid was introduced with cooling over a 20-min period.[15a] After an additional 20 min at ambient temperature, the solution was poured into 600 ml of water and stirred for 15 min. The crystalline material was filtered and the remaining product was isolated from the filtrate with ether,[15b] affording 30.9 g (94%) of combined solid material consisting of a nearly 1:1 mixture of bromo ketones **17** and **18**.

In another experiment, a pure sample of bromo ketone **18**, mp 97–98°, was obtained by recrystallization: ir λ_{max}^{KBr} 5.81 (CO), 6.83, 7.19, 7.29, 7.99, 8.52, 9.24, 9.64, 10.78, and 13.89 μ; nmr $\delta_{TMS}^{CCl_4}$ 4.77 (d, J = 11.2 Hz, H-6), 1.13 (d, J = 5.8 Hz, C-7 CH_3), and 1.35 and 1.10 ppm (C-4 CH_3's).

Anal. Calcd for $C_{12}H_{19}BrO$: C, 55.60; H, 7.39; Br, 30.83. Found: C, 55.9; H, 7.4; Br, 30.85.

A purified sample of bromo ketone **17** was obtained as an oil upon chromatography of the noncrystalline residue of the aforementioned experiment: ir λ_{max}^{film} 5.86 (CO), 8.01, 8.57, and 8.85 μ; nmr $\delta_{TMS}^{CCl_4}$ 4.20 (d, J = 2.4 Hz, H-6), 1.31 (d, J = 5.7 Hz, C-7), and 1.31 and 1.02 ppm (C-4 CH_3's).

A pure sample of the oily bromo ketone **17** (140 mg) was stirred with 3 ml of carbon tetrachloride and 6 ml of acetic acid containing 3 drops of concentrated HBr for 2 hr at room temperature to effect equilibration.[15a] The nmr spectrum revealed an 85:15 ratio of ketones **17** and **18** after this time. After an additional 17 hr, the ratio of **17** to **18** had decreased to 60:40. Under these conditions, the crystalline bromo ketone **18** was virtually unchanged after 32 hr.

4,4,7-Trimethyl-3a*c*,7a*r*-dihydro-5(4H)-indanone (20).[15d]—The 30.91-g sample of bromo ketones **17** and **18** described above and 34.8 g of calcium carbonate in 310 ml of N,N-dimethyl-

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acetamide was heated at reflux for 35 min,[15a] cooled, and filtered.[16] The product was isolated with heptane,[15b] affording 18.3 g (87%) of material containing 78% of ketone **20** according to the gas chromatogram. Chromatography on silica gel afforded 14.3 g (63%) of enone **20**: ir λ_{max}^{film} 5.98 (CO), 6.13 (C=C), 7.22, 10.99, and 11.49 μ; $\delta_{TMS}^{CCl_4}$ 5.61 (vinyl H), 1.83 (vinyl CH_3), and 1.11 and 1.02 ppm (C-4 CH_3's).

The oxime derivative exhibited mp 134–135.5° after recrystallization from methanol.

Anal.[15c] Calcd for $C_{12}H_{19}NO$: C, 74.56; H, 9.91; N, 7.25. Found: C, 74.3; H, 10.1; N, 7.2.

4,4,7*t*-Trimethyl-3a*c*,6,7,7a*r*-tetrahydro-5(4H)-indanone (21).[15d]—A solution of 10.41 g (58.4 mmol) of ketone **20** in 100 ml of ethanol was stirred under 1 atm of hydrogen with 7.8 g of W-2 Raney nickel[18] for 3 hr at room temperature. The mixture was filtered and the filtrate was concentrated, affording a mixture of alcohols and ketones which was oxidized using 8.1 ml of Jones reagent[13] to give 10.28 g (98%) of ketone **21** (67% pure by gas chromatography). The ketone **21** (6.47 g) was isolated by preparative gas chromatography: ir λ_{max}^{film} 5.86 (CO), 6.83, 6.89, 7.10, 7.21, 7.32, 8.49, 8.90, and 9.48 μ; nmr $\delta_{TMS}^{CCl_4}$ 0.93 (d, J = 5.7 Hz, C-7 CH_3), and 0.98 and 1.15 ppm (C-4 CH_3's).

The oxime derivative **22**, mp 101–102°, was prepared in 87% yield. The analytical sample exhibited mp 102–103° (white needles) after crystallization from methanol and mp 110–111° (white powder) after sublimation.

Anal.[15c] Calcd for $C_{12}H_{21}NO$: C, 73.80; H, 10.84; N, 7.17. Found: C, 73.8; H, 10.9; N, 7.3.

Bromination of Ketone 21.—A 26-mg sample of ketone **21** was brominated in acetic acid according to the procedure described above. The product was extracted with carbon tetrachloride and subjected to nmr analysis without purification: nmr $\delta_{TMS}^{CCl_4}$ 4.10 (d, J = 12 Hz, H-6), 1.28, 1.02 (C-4 CH_3's), and 1.02 ppm (d, J = 8 Hz, C-6 CH_3).

Fragmentation of Oxime 22.—The previously described procedure was employed on 3.80 g of oxime **22**, affording 3.23 g (94%) of a mixture containing 75% of the isopropylidene isomer **23** and 19% of the isopropenyl isomer **24**. This mixture was separated by chromatography on silver nitrate impregnated silica gel[17] and preparative gas chromatography.

The isopropylidene isomer **23** displayed ir λ_{max}^{film} 4.43 (CN), 7.25, 7.94, and 8.08 μ; $\delta_{TMS}^{CCl_4}$ 1.62 (vinyl CH_3's) and 1.03 ppm (d, J = 6.4 Hz, CH_3).

The isopropenyl isomer **24** displayed ir λ_{max}^{film} 3.23 (vinyl CH), 4.43 (CN), 6.09 (C=C), 7.23, 8.79, and 11.20 μ; nmr $\delta_{TMS}^{CCl_4}$ 4.67 (m, vinyl H), 1.70 (vinyl CH_3), and 1.06 ppm (d, J = 5 Hz, CH_3).

Anal.[15c] Calcd for $C_{12}H_{19}N$: C, 81.30; H, 10.80; N, 7.90. Found: C, 81.2; H, 10.8; N, 7.85.

***rel*-3(*R*)-[2(*R*)-Isopropenyl-1(*R*)-cyclopentyl]butanal (25).**—The previously described reduction was employed on 677 mg of nitrile **24**, affording 669 mg (97%) of aldehyde **25** (97% pure by gas chromatography): ir λ_{max}^{film} 3.24 (vinyl CH), 3.68 (aldehyde CH), 5.80 (CO), 6.10 (C=C), 7.08, 7.25, 9.89, 10.63, and 11.24 μ; nmr $\delta_{TMS}^{CCl_4}$ 9.75 (t, J = 2 Hz, aldehyde H), 4.75 (m, vinyl H's), 1.90 (vinyl CH_3), and 0.97 ppm (d, J = 5.2 Hz, CH_3).

6*t*-Methyl-2-methylene-1c*H*,7r*H*-bicyclo[5.3.0]decan-4*c*-ol (26).[15d]—A 669-mg sample of aldehyde **25** was chromatographed on 75 g of silica gel. Elution with 2–5% ether–benzene afforded 586 mg of alcohols **26** and **27** (a 98:2 mixture by gas chromatographic analysis): ir λ_{max}^{film} 2.96 (OH), 3.25 (vinyl CH), 6.11 (C=C), 7.21, 7.59, 8.40, 9.00, 9.45, 9.64, 9.79, 10.03, 10.25, 10.59, 10.80, 11.27, 12.45, and 12.54 μ; nmr $\delta_{TMS}^{pyridine}$ 4.85 (OH), 4.81 ($\Delta\nu$ = 5 Hz, vinyl H's), 3.99 (m, H-4), and 0.85 ppm (d, J = 6.4 Hz, C-6 CH_3).

Anal.[15c] Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 79.95; H, 11.3.

2*t*,6*t*-Dimethyl-1c*H*,7r*H*-bicyclo[5.3.0]decan-4-one (30).[15d]—A solution of 396 mg (2.20 mmol) of alcohol **26** in 5 ml of ethanol was stirred under 1 atm of hydrogen with 168 mg of platinum oxide for 11 hr at room temperature. The mixture was filtered and concentrated to give a mixture of alcohols **28** and **29**. This material was oxidized with 0.50 ml of Jones reagent,[13] affording 379 mg (96%) of a 64:36 mixture of ketones **16** and **30** which was separated by preparative gas chromatography. The major ketone was identified as the *trans* isomer **16** by comparison with the previously prepared material. The minor isomer **30** displayed the following spectral characteristics: ir λ_{max}^{film} 5.89 (CO), 7.01, 7.30, 7.49, 7.80, and 8.85 μ; nmr $\delta_{TMS}^{CCl_4}$ 1.02 ppm (unresolved, $W_{1/2}$ = 11 Hz, CH_3's).

The 2,4-DNP derivative exhibited mp 150–151.5° after recrystallization from ethanol.

Anal.[15c] Calcd for $C_{18}H_{24}N_4O_4$: C, 59.99; H, 6.71; N, 15.55. Found: C, 59.9; H, 6.7; N, 15.6.

Registry No.—**3**, 18366-35-3; **3** semicarbazone, 18366-36-4; **4c**, 22202-03-5; **4c** semicarbazone, 22202-04-6; **5c**, 22202-05-7; **5c** oxime, 22202-06-8; **6**, 22202-07-9; **7**, 22202-08-0; **8**, 22202-09-1; **9**, 22202-10-4; **10**, 22202-11-5; **10** 2,4-dinitrophenylhydrazone, 22202-12-6; **11**, 22202-13-7; **12**, 22202-14-8; **13**, 22202-15-9; **14**, 22202-16-0; **15**, 22202-17-1; **15** 2,4-dinitrophenylhydrazone, 22202-18-2; **16**, 22202-19-3; **17**, 22202-20-6; **18**, 22202-21-7; **20**, 22202-22-8; **20** oxime, 22202-23-9; **21**, 22202-24-0; **22**, 22202-25-1; **23**, 22202-26-2; **24**, 22202-27-3; **25**, 22202-28-4; **26**, 22202-29-5; **27**, 22202-30-8; **30**, 22202-31-9; **30** 2,4-dinitrophenylhydrazones, 22202-32-0; 6*t*-Bromo-4,4-dimethyl-3a*c*,6,7,7a*r*-tetrahydro-5(4H)-indanone, 22202-33-1.

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